Optical Variability and Bottom Classification in Turbid Waters: Phase II

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LONG-TERM GOALS

Real-time determination of the optical and bathymetric climate available for operation of various naval assets in the coastal zone using a mixture of AUV, ROV, surface-vessel, fixed moorings/towers, and air/space-borne observational assets. Advanced heat-budget modeling applicable to coastal regions as well as methods for early detection of *K. brevis* (red-tide) and other algal blooms. Remote determination of inherent optical properties and bottom characteristics will be accomplished for input and validation data for predictive visibility, heat budget, and primary production models and for use in asset selection for naval operations.

OBJECTIVES

The development of optical methodologies valid for Case II coastal waters for the remote determination of water and bottom optical properties including visibility, water amd bottom optical absorption, algal concentrations, bathymetry, bottom albedo, vegetation cover, and bottom structure are being pursued. These include interpretation of hyperspectral, high-resolution imagery from aircraft and satellites, development and deployment of suites of small instruments on remotely operated and autonomous underwater vehicles (ROVs, AUVs) and a multi-disciplinary network of moored sensors, and development/application of radiative transfer models and algorithms for predicting optical properties and extracting information from the remote data. Effects of vertical structure in the optical properties (e.g. river plumes, suspended sediments) and turbidity must be recognized for the data retrievals to be accurate, and the instruments and methodologies necessary to quantify such structure will be developed and utilized on underwater vehicles and moorings.

APPROACH

We have developed models for inverting hyperspectral data from air- and space-borne sensors in vertically homogeneous waters and estimating absorption, back-scattering, and beam-attenuation coefficients, as well as bathymetry and bottom albedo (Lee et al. 1999, 2000). We have also presented methodologies for advanced coastal water heat budget modeling (Warrior et al. In prep.) and early detection of red-tide and other algal blooms (Carder et al. Submitted). These can be used as initial or

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boundary conditions for heat-budget, primary production, visibility models and to predict where certain mine-counter-measure assets can productively be deployed or not given an adequate means of validating the model retrievals and simulating the performance requirements of the assets.

Water clarity, bathymetry, and bottom albedo are critical variables affecting optical searches for objects in the water column or on the bottom. Object contrast with the background optical field or its 3-dimensional shape can be used in object-classification schemes. We are using elastic and inelastic scattering and active and passive systems for use in object-classification schemes, and we are evaluating how system performance degrades with increased turbidity, range, and optical structure (e.g. layers) over a variety of bottom types.

Our efforts have supported Hycode, Ecohab, and FSLE experiments on the West Florida shelf with mutle-vessel teams acquiring atmospheric and in-water optical measurements. In addition, we have designed, constructed, and installed the first Autonomous Marine Optics Sensor (AMOS) station which relays water property and Rrs measurements in real time to our laboratories via free-wave radio.

We have developed several optical packages for deployment on ROVs and AUVs to measure the optical properties of the water column and bottom to provide an assessment of the accuracy of the model assumptions and retrieval values from air-borne sensors, and we have deployed these as part of the CoBOP and HYCODE field activities. Several of these (e.g. Bottom Classification and Albedo Package, BCAP, and Real-Time Ocean Bottom Optical Topographer, ROBOT) have been developed and tested on ROVs or AUVs (Carder et al., 2000; Costello and Carder, 1997, 2000a, 2000b; Costello et al., 1998a, 1998b; Hou et al., 2000; Peacock et al., 1998; Renadette et al., 1997, 1998).

This project utilizes BCAP, a suite of optical instrumentation developed under previous ONR funding, to acquire the hyperspectral database required to deconvolve the components of the underwater and water-leaving light fields (Carder et al., 1999; Costello et al., 1997; English et al., 1998; Hu et al., 1998, 1999; Ivey et al., 1998, 1999; Patch et al., 1998). *In situ* instrumentation includes a 512-channel upwelling radiometer, a 512-channel downwelling irradiometer, two 6-channel, intensified bottom cameras, a single-channel, intensified bottom camera, a dual-laser, optical altimeter/chlorophyll probe, and commercial-off-the-shelf (COTS) instrumentation to measure attenuation, absorption, backscattering. Two BCAP systems have been configured for deployment on our ROSEBUD remotely operated vehicle (ROV), the Ocean Explorer class autonomous underwater vehicles, and USF's Center for Ocean Technology (COT) ROVEX vehicle.

WORK COMPLETED

- Fluorescence imagery of the bottom, including natural and man-made objects, has been secured at several sites using an intensified video camera and a narrow-band-pass (NBP) filter centered at 685 nm from both our ROV and the Ocean Voyager II AUV.

- We participated on several cruises last year, collecting Rrs, absorption, and pigment data on 1 NRL and 5 ECOHAB cruises, with the addition of slow-drop ROV BCAP measurements on 4 R/V Subchaser cruises, and full participation in CoBOP cruises using R/V Suncoaster and R/V Subchaser at Lee Stocking Island supporting slow-drop, AUV (ROBOT, BCAP, SIPPER), and ROV BCAP measurements of AOPs, IOPs, bottom albedo, microtopography, and verticle variability to condition HydroLight for evaluation of vertical structure on Rrs (0^+) and $E_d(z)$ models. These cruises accompanied many aircraft over-flights of AVIRIS and PHILLS as well as providing a variety of

optical conditions to 200 km off the west Florida coast.

- We designed, constructed, and installed the first Autonomous Marine Optics Sensor (AMOS) station in Tampa Bay off Port Manatee. AMOS relays real-time Rrs and in-water optical measurements to our laboratories.

- We developed methodology to detect red-tide (*Karinia brevis*, formerly known as *Gymnodinium breve*) from space (Carder et al. submitted).

- We have developed an improved heat and salt-budget model for shallow waters. The model incorporates spectral absorption coefficients for both the water column and the bottom and is a significant improvement in accuracy versus the traditional Princeton Ocean Model (POM) for shallow water regions.

- Our group has been active publishing our results. Peer-reviewed publications in print, in press, and submitted this year total 13 (see below).

RESULTS

Bottom albedo affects the water-leaving radiance on the WFS out to 45 km offshore. Derived absorption and chlorophyll using standard algorithms are nearly doubled by bottom effects. A model to remove these perturbations for use with SeaWIFS and MODIS data has been developed (Carder and Chen, submitted).

Major progress in nowcasting the optical properties of the water column, water depth, and bottom albedo from remotely sensed data has been made this past year, including the Lee et al. (1999, 2000) publications inverting hyperspectral R_{rs} data for homogeneous water columns and nowcasting of bathymetery and optical properties for the turbid waters of Tampa Bay (Fig. 1, 2).

Due to the high attenuation of 685 nm radiation by water, essentially no solar radiation at that wavelength is reflected from below a few meters of depth (Costello et al., 1998a). However, the attenuation of the blue-green radiation band that pumps chlorophyll fluorescence at that wavelength is lower by about a factor of twenty (Costello et al., 1998b). This has been exploited to produce high-contrast, NBP imagery of non-fluorescing objects silhouetted against the natural, solar stimulated (fluorescing) background for depths from 6 – 25m. The ability to acquire NBP imagery is, however, a function of the water IOPs within the pass band. Fluorescence imagery could not be obtained, for example, during an ROV deployment below 30m off Sombrero Key. However, in 25 m water depth in the Dry Tortugas and the Bahamas, there was bottom fluorescence sufficient to acquire imagery in the 685 nm band and even in a band centered at 730 nm. The parameterization of the method considering different bottom types and the spectral irradiance available at depth is underway.

Red-tide blooms and their precursors (iron-rich Saharan dust, Trichodesmium blooms, Walsh et al. 2001) can now be detected from space (Carder et al. submitted). Future work will focus on removal of bottom-effects in shallow waters to allow early bloom detection.

Our heat and salt budget model accurately predicted a large temperature feature measured of Sarasota, FL. (Warrior etal. in prep.) The feature could not be reproduced using the traditional (transparent bottom) POM.

IMPACT/APPLICATIONS

Nowcasting the optical properties of the water column, water depth, and bottom albedo from remotely sensed data presents widespread benefits and also significant logistical challenges. One challenge is to understand the likely range of variables for a particular environment in order to streamline model computations. We recently published a neural network inversion scheme (Lee et al. 1998c) which will be tested on a training set derived for the Lee optimization approach using a subset (0.5-1%) of scene points for the Tampa Bay and Sarasota imagery. Since optimization is accurate (D~8-10%) but slow (~5 seconds/pixel on an SGI O2), and neural networks are almost instantaneous (once trained) but less accurate (D~12-14%), this approach provides a practical method to deliver results in a rapid manner even for denied-access areas. Once a NN is trained for a given region it can be used rapidly as long as the optical parameters remain within the training range. Critical regions within the derived bathymetric scene can be evaluated as a test using the optimization approach and measured field data when available. BCAP, ROBOT, an optical slow-drop package, and hydro-cast data will be used to validate the derived products of these and other remotely sensed data sets, especially those obtained near the USF ECOHAB/HyCODE buoys and towers. The geology group (Howde et al.) has made side-scan sonar and high-resolution, multibeam bathymetry maps and sand/hard-bottom characterization of these sites for use in analyzing the nowcasting results.

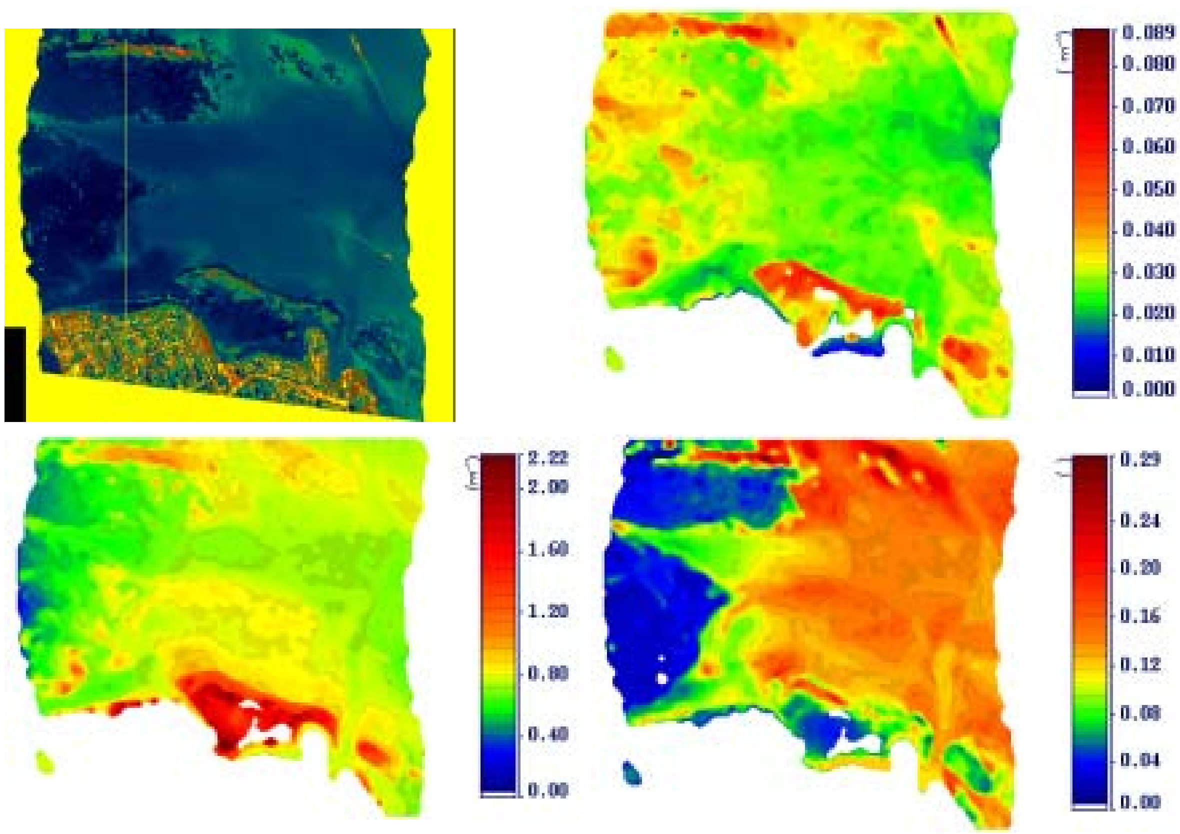

Figure 1. Calculated IOPs at 440 nm for the area shown at the upper left: Backscatter (upper right), attenuation (lower right), and bottom albedo (lower left).

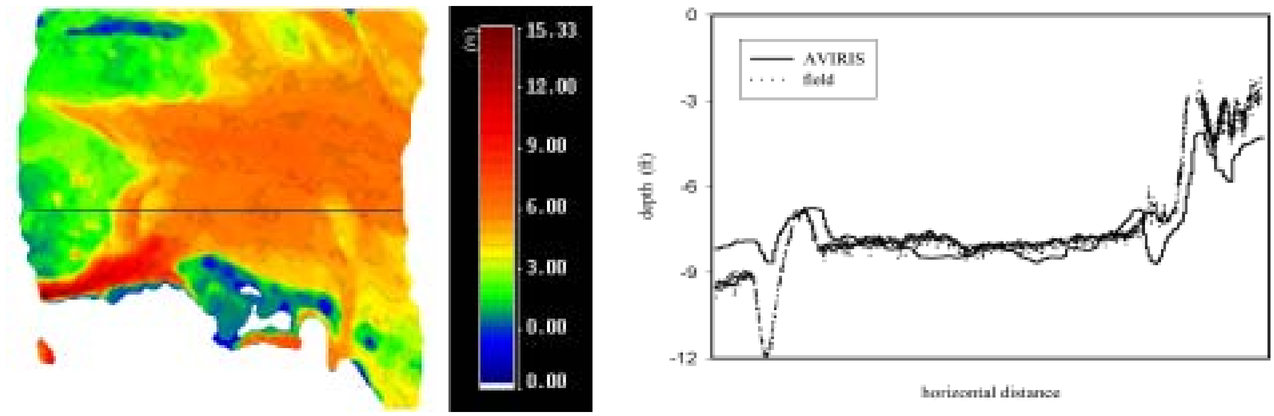

Figure 2. Calculated bathymetry (left) and a comparison with field measurements (right) along the indicated transect line. See text for discussion.

For AVIRIS, PHILLS, and COIS scenes over structured water columns (e.g. Tampa Bay plume, suspended sediment plumes, bubbles) a real-time approach is being implemented by instrumenting the buoys with DURIP-funded optical sensors. Since these provide optical properties with depth and will be functioning during both clear and stormy weather, nowcasting retrievals from the buoy R_{rs} measurements above the ocean can be compared to measured depth, albedo and water-column optics to determine when and how algorithms fail. These data are critical validating and improving algorithms.

Solar-stimulated fluorescence imagery of the bottom can be acquired in any area where the depth is sufficient to effectively quench 685 nm reflected solar radiation and where blue-green radiation penetrates sufficiently to stimulate 685 nm fluorescence to a level which allows image formation by the sensor. The significance is two-fold: first, since the bottom is the source, the imagery acquired is free from the backscattered path radiance generally associated with contrast degradation in underwater imagery (Pratt et al,. 1997); second, animals and man-made objects do not, generally, fluoresce at 685 nm. Given the appropriate environmental parameters, this makes possible the visualization of bottom objects which may not be apparent using either active or passive reflection (elastic) imaging techniques. Applicability ranges from assessment of the standing stock of sponges to underwater mine detection.

TRANSITIONS

A number of instrument systems and deployment platforms developed under this funding have transitioned from prototype engineering mode to operational scientific mode.

1. The BCAP package has been transitioned from the prototype Ocean Voyager II AUV to the OEX class AUVs and the ROVEX vehicle.

2. The R/V Subchaser is now routinely utilized for the deployment of underwater vehicles. Co-operative work has been performed with several ONR-funded efforts as well as with work funded through NRL-Stennis, NRL-Washington, and NASA.

3. The ROSEBUD ROV has transitioned from a test-bed platform to a working platform. During the CoBOP and HyCODE field campaigns, for example, the vehicle was used to

acquire over 2,500 hyperspectral irradiance/radiance spectra and multi-spectral elastic and inelastic bottom imagery.

4. Several payload modules for ROVEX and/or the Ocean Explorer fleet of AUVs have been deployed and are now available to support field operations. These include ROBOT and BCAP (described here) and three other payloads developed at USF: SIPPER and DLS (marine particle enumeration systems) and SEAS (a micronutrient and spectrophotometric pH sensor).

RELATED PROJECTS

This project benefits from an association with the ONR project Coastal Benthic Optical Properties (CoBOP). CoBOP field exercises allow the opportunity to deploy hardware systems developed under this funding while benefiting from significant ancillary data from other CoBOP investigators.

Similar symbioses exist with the ONR Bottom Boundary Layer project, the ONR HyCODE project, and with the multi-agency ECOHAB effort which have targeted the west Florida shelf as a study site. Our co-operative participation enhances these projects and makes complementary data available to us for our work.

Efforts within our group toward model inversion (funded through ONR/CoBOP and NASA) utilizing remote sensing reflectance provides bathymetry and water optical properties.

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